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SANITIZED VERSION OF THE CONSEQUENCES OF UF_6 RELEASES FROM THE DIFFUSION CASCADE (JANUARY 25, 1974)

(SANITIZED VERSION OF CRD DOCUMENT #KY-L-693)

Compiled by
S. G. Thornton
Environmental Management Division
OAK RIDGE K-25 SITE
for the Health Studies Agreement

April 23, 1996

Oak Ridge K-25 Site
Oak Ridge, Tennessee 37831-7314
managed by
LOCKHEED MARTIN ENERGY SYSTEMS, INC.
for the U.S. DEPARTMENT OF ENERGY
under Contract DE-AC05-84OR21400

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Date: January 25, 1974 Report No.: KY-L-693

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THE CONSEQUENCES OF UF_6 RELEASES FROM THE DIFFUSION CASCADE

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Paducah Gaseous Diffusion Plant
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THE CONSEQUENCES OF UF_6 RELEASES FROM THE DIFFUSION CASCADE

INTRODUCTION

Because of future operation of the cascade at pressures above atmospheric and increased awareness of and concern with air pollution in general, it is desirable to consider the potential hazard to the public of UF_6 releases from the cascade. This report will attempt to evaluate the many factors relating to a UF_6 release from the cascade proper and to determine if special equipment or procedures are necessary to protect the general public in the event of a large release.

To answer this question, we will establish the "maximum credible release" from the cascade and estimate the consequences of such a release under adverse meteorological conditions. The term "maximum credible release" refers to the maximum amount of UF_5 which it is anticipated could be released by any single credible incident. We will attempt to be realistic about possible incidents and consider those which history and knowledge of the systems and processes indicate are credible. For example, we will not propose the escape of the total inventory of one cell unless there seems to be some credible mechanism to explain how such a loss might occur. We will not now consider natural events such as earthquakes and tornadoes. These could be disasters regardless of cascade pressure and would be as likely to render containment systems useless as to release UF_6 from the cascade in the first place.

We would like to point out that a gaseous diffusion plant is little different from other chemical plants processing, for example, some of the insecticides like aldrin, dieldrin, and parathion or, perhaps, coal tar pitch volatiles. The threshold limit values for these materials are 0.1 to 0.25 mg/M^3 while for uranium[2] the value is 0.2 mg/M^3. Or, one might be willing to assume the risks are similar to a petroleum refinery. In this case, the environmental damage may come from an explosion, but the results could be no less serious. In reality, it is believed that the examples cited are valid comparisons and that the risks to be faced by diffusion plant operators are faced daily by hundreds of other processing plants. Convincing the public that the diffusion plant is just another ordinary "factory" may take some doing. But it is believed that, while some weight might be given to the nuclear connotation, we should evaluate the situation on a strictly technical basis. That is what has been done.

With operation of the cascade at pressures above atmospheric, the escape of UF_6 into the atmosphere becomes increasingly possible. Relatively minor leaks, which previously resulted in air inleakage to the cascade, now become potential sources of UF_6 outleakage. The vast majority of these leaks will be of such a magnitude as to pose no problem whatsoever off-site. On-site, however, inside the cascade buildings, they would be a problem due to health, safety, and possibly economic factors. For a variety of reasons, then, such leaks must be kept small both individually and cumulatively. From over twenty years of experience, this type of leak can be anticipated very well as to location, magnitude, and frequency. It is known that likely sites will be bellows, expansion joints, valve packing, broken instrument lines, weld cracks, seals, etc. Steps will be taken to minimize and/or control such leaks; for example, covered and buffered expansion joints, upgraded welding, cap gland seals, etc.

These routine-type leaks cannot, however, be eliminated, and there will remain a need for outleakage detection. Thus, UF_6 leak detection equipment capable of sensing a few parts per million of uranium in the atmosphere will be installed throughout the cascade. This will provide detection of leaks so small they might otherwise escape detection and will ensure rapid detection of larger leaks.

In contrast to these minor leaks, the large gas compressors, with their relatively vulnerable bearings and seals, do present a possibility for large UF_6 releases. In the past, accidents have happened that could possibly have resulted in large releases if the system pressures had been as high as is currently projected for CUP operations. Such failures, however, will generally be preceded by increased vibration prior to complete failure. Vibration detection equipment is presently installed in C-310. Such equipment, providing low- and high-level detection with alarm and automatic shutdown, has been budgeted for the rest of the cascade. This detection and shutdown capability will greatly reduce the probability of rotating equipment malfunctions proceding to the point of serious system rupture. Experience shows that this probability is very small already.

The maximum credible release of UF_6 from the cascade under CUP conditions is estimated to be 3000 pounds, but the probability of such a leak is very small. Even in the event of such a release, the downwind uranium and fluoride concentrations would be sufficiently low so that no harmful effects would occur to the surrounding population. Therefore, there is no necessity for additional containment mechanisms or procedures for the Paducah cascade proper. Auxiliary systems and feed and withdrawal operations will be covered in a future study.

PAST MAJOR INCIDENTS

Twenty-odd years of operating experience, some of it above atmospheric pressure, is a good basis for the prediction of future accidents and the release of UF_6. During the years 1960-1961, most of the cells in units 2, 3, and 4 in both C-333 and C-337 operated above atmospheric pressure for varying periods of time up to 21 months. Between 1957 and 1964, ten cells of 00 equipment operated above atmospheric pressure for periods varying from two to seven years. Tate and Breidert[2] and Tate and Cope[3] did studies of this high-pressure operation and concluded that there was no increase in equipment failure rates attributable to the higher pressure. On the basis of material release reports, there was only one UF_6 release of any size from on-stream cascade operation during this entire period. Following a compressor seal failure in C-333, five pounds of UF_6 was released in October 1960.

There have, however, been incidents which either released or, under other circumstances, could have released large amounts of UF_6. These were the C-310 fire, the C-337 incident, and two compressor failures, one in C-335 and the other in C-331. These incidents are discussed below.

C-310 Fire

The C-310 fire[4] in November 1956 originated at a product withdrawal compressor which was operating above atmospheric pressure. A seal failure permitted the escape of a small quantity of UF_6 and fluorine. A vigorous reaction occurred between the escaping gases and lube oil on the compressor surfaces. The resulting fire caused the rupture of the lube oil supply line. With the additional fuel, the fire grew and ignited the roof which eventually collapsed along with the side walls above the cell floor. In spite of the extensive damage to the structure and equipment, the release of UF_6 was insignificant. Aside from the initial release at the pump, there were no other releases as a result of the fire. The considerable, general damage prevented an accurate estimate of the initial release.

As a result of this incident several steps were taken to reduce the probability of serious fires in any of the cascade buildings. Chief among these was the installation of a water sprinkler system with fusible link heads throughout the cascade. Also, remotely operated valves were installed in the lube oil lines to permit isolation or drainage of the gravity head supply tanks in case of emergency. The effectiveness of the sprinkler system was demonstrated in the C-337 incident which is discussed later.

Compressor Failures in C-331 and C-335

The two compressor failures occurred at C-335-2.2.8 in September 1967[5] and at C-331-4.5.10 in May 1968.[6] The C-335 incident occurred on-stream and the other off-stream. Both failures involved deblades, heavy rotor end rub, high vibration, and bearing failure. In the C-335 incident, the entire seal assembly at the A-end of the compressor was flailed out permitting the entrance of wet air. In the C-331 failure, the compressor end bell containing the B-seal was separated from the compressor shell allowing entry of wet air. Reports of the investigations of these incidents indicate no UF_6 releases occurred.

These two incidents were major factors in the decision to employ vibration detection and automatic shutdown which has now been budgeted for the entire cascade. Also, there have been operational changes which are intended to minimize the recurrence of similar incidents. These changes were intended to reduce the occurrence of rotor end rub which would likely be a key factor in incidents of this type. It is also important to note that in both of these incidents the initial vibration would probably have been sufficient to shut down the cell before major damage if the planned detectors had been in use at that time.

C-337 Incident

In December 1962, a low intensity rupture of cell equipment occurred in C-337-1.3.

Estimated damage from equipment rupture and the associated fire was two million dollars. Approximately 5000 pounds of UF_6 was lost. The sprinkler system, installed following the C-310 fire, was instrumental in controlling the damage.

It is not possible to know exactly what occurred during this incident,

At some point, inleakage of coolant occurred further fueling the reactions and ultimately over-pressuring the system which resulted finally in the system rupture.

Key factors in the extensive system rupture were the presence of large quantities of coolant and the limited volume for its expansion to vapor after escape from the coolant system. Another factor was failure to detect or understand the abnormalities which were occurring so that preventive measures could be taken before the incident ran its full course.

Following this incident, a review of plant drying pro- cedures was made and an investigation of the hazards was initiated. Ultimately, the chemistry involved was defined and analytical instrumentation developed to monitor the progress of the treatments. Revised operating instructions were issued and further modified as information was developed. The principal modifications were as follow:

1. Coolants are removed.

2. Stage temperatures are monitored and recorded continuously to provide a better, more rapid visual indication of potential operating abnormalities.

3. The maximum temperature in any part of a stage does not exceed

4.

5. Disposal of cell contents after completion of treatment is carried out in such a manner as to prevent

accumulation of explosive concentrations of reactants or reaction products in either gaseous or condensed phases.

6. Instrumentation, such as gas chromotography, is used to monitor the course of the reaction and to detect abnormalities.

The knowledge gained from this incident along with the revised operating procedures should be adequate to prevent similar incidents in the future. Since this is an off-stream operation, conditions within the cell can be determined satisfactorily with careful temperature monitoring and the use of analytical instruments throughout the course of the operation. Twelve years of subsequent operation attest to the success of these modifications, and it is concluded that the risk of again releasing a major amount of UF_6 as a result of a similar incident can be controlled satisfactorily. To put it another way, the frequency of occurrence (and so the probability) of this type of incident was initially quite small. The revised operating procedures, the monitoring instrumentation, and the experience of the C-337 incident can only serve to further reduce the probability materially.

POSSIBLE INCIDENTS

Previously we have discussed four major incidents which have actually occurred at the Paducah Plant. This emphasis on real incidents is justified in view of over twenty years of operating experience. Future accidents, however, are not limited to those which have already occurred, and other possibilities need to be discussed.

Lube Oil Failure

The function of the cascade lube oil systems is to lubricate motor and compressor bearings. Failure to do this will lead ultimately to bearing failure and high vibration. With high vibration, there is a distinct possibility of bearing and seal damage and rupture of cascade equipment. The results could be similar to those in the two compressor failures described earlier. While there are adequate safeguards to prevent the failure of the lube oil system, one can never totally eliminate bearing failures since bearing life, even with ideal lubrication, is not infinite. However, the vibration detection system to be installed should significantly reduce the possibility of a major compressor disaster as the result of a bearing failure.

Massive Coolant Releases

It was postulated that the C-337 rupture of cell equipment was due to overpressure from the release of coolant. That was an off-stream operation and the released coolant was confined to one cell volume. On stream, a similar rapid release of the total cell coolant is extremely unlikely because of the extensive cooler failure which would be necessary. Even if it occurred, cascade rupture would not be expected because the coolant would not be confined to a small volume but would be free to spread to other cells unless the leak was of massive proportions. For example, if one of the cooler tubes were to break in two so that liquid coolant was flowing to the process system from both ends of the broken tube, a volume of vaporized coolant about 88 cubic feet would be added to the cell per second.

While a leak of this size would not be serious, were the total inventory of one 000 cell coolant system to be released, the coolant volume would be 2.7 cell volumes. Except for the C-337 incident referred to above, there have only been very minor coolant releases, usually caused by erosion from solids in the coolant system. There appears to be no credible mechanism to cause the multiple tube failure that would be required to overpressure an on-stream cell.

Explosive Reactions

Coolant and either fluorine or ClF_3 can react explosively. To produce such explosions, however, there are minimum pressure and composition requirements.[8] Furthermore, the reactions are not spontaneous but require initiation by heat or spark.

There are, of course, frequent small coolant leaks into the process gas. Such coolant moves upstream and pockets in the purge cascade.

Other Reactions

Under proper conditions, UF_6 and aluminum can react vigorously; however, a high temperature- far above normal operating conditions, is needed to initiate such a reaction. This high temperature can be generated by the friction sometimes associated with equipment failures.

Regardless of the mode of initiation, the aluminum reactions are not explosive, and extensive rupture of equipment as a direct result is unlikely although burning or melting a hole is possible. The more likely result would be equipment imbalance leading to vibration. Ultimately, extensive bearing and seal damage would be possible such as that experienced in the two compressor failures discussed earlier.

MAXIMUM CREDIBLE RELEASE

In our discussion of actual and possible major ruptures in cascade equipment, it was in most instances possible to indicate how steps have been taken, safety devices employed, procedures rewritten, etc., to prevent specific incidents from occurring in the future. As has been indicated, there is one serious accident type which will continue to pose a threat despite preventive efforts. This is the failure of a compressor or compressor component. Normally, these incidents are expected to lead first to increased vibration before major damage occurs. Vibration detection, especially with automatic shutdown, will go a long way toward eliminating serious equipment rupture and UF_6 releases. While the vibration detection system will prevent most catastrophic failures, it is possible with the massive equipment and rotational speeds involved for major damage to occur very quickly, perhaps before shutdown steps become effective.

Failures of this type do not follow any set pattern. They may be initiated by a variety of means. At some point they may involve any or all of the following in widely varying degrees of severity: compressor deblade, destructive reactions, seal failure up to complete wipeout of the seal cavity, rupture of the compressor shell, and rupture of system piping. The order of occurrence may vary and the total elapsed time may be extremely brief. These factors are important and bear directly on the magnitude of the resulting release.

For example, we postulate the following accident. A bearing fails in a 000 cell operating The whipping shaft results in complete destruction of the B-seal leaving an annular 37 in.^{2} hole around the shaft. The compressor completely deblades. Time zero is defined as the instant when the hole has reached 37 in.^{2}, the compressor has debladed, but the pressure is still

This accident was modeled by the Operations Analysis Department at ORGDP in terms of a small square cascade (10 stages) fed from two infinite reservoirs of high and low pressure at both the top and bottom of the cascade. The transient behavior of the leak was summarized as follows. "In a period of 0.376 seconds the leak flow to atmosphere is reduced to zero and the cumulative leak is 5.8 pounds of UF_6. The reason the loss is so low is that the resistance of the debladed compressor to flow is very low relative to the leak to atmosphere. Consequently, the inventory of the converter above the debladed compressor rushes to the converter below the debladed compressor before much UF_6 is lost."[10]

While one could perhaps question the timing assumptions and, consequently, the exact magnitude of the release, it is clear that the sequence of events is critical and that very low losses are possible.

In the accident postulated above it is difficult to imagine anything other than total compressor deblade and pressure equalization prior to total seal destruction. However, in the interest of pursuing the examination, we have assumed the same damage but with continued pumping by the compressor. Accompanying and following such an incident would be many indications of a serious problem, but a manual rather than automatic shutdown is assumed. Allowing time to investigate and establish that a major incident has occurred before initiating cell shutdown, it is assumed that the pumping of UF_6 continues for three minutes before remedial actions become effective.

This accident was also modeled by the Operations Analysis Group at ORGDP.[11] Initially, the leak rate would be 2000 pounds of UF_6 per minute. With passing time, the process pressure would drop lowering the leak rate significantly. The cumulative release for three minutes would be approximately 3000 pounds.

This is what we consider to be the maximum credible release. Let it be understood that while this accident is credible the assumed circumstances we consider to be highly unlikely, and we do not intend to suggest that such an accident is to be expected. In our analysis, however, it is possible.

CONSEQUENCES OF A 3000-POUND RELEASE

To estimate the consequences of a 3000-pound release of UF_6 inside one of the 000 buildings, we will assume the following conditions and mode of release. The building is on maximum ventilation which supplies 6.36×10^6 cfm of air to the cell floor. This is approximately one cell floor volume each ten minutes, and we will assume that the concentration of any material in the cell floor air is reduced by a factor of one-half per ten-minute period. In other words, one-half of the material in the cell floor air will be purged from the building in ten minutes. This is not to imply complete mixing of the UF_6 with the total cell floor air. Air is being supplied to and exhausted from all areas of the cell floor simultaneously. The assumption is thus reasonable regardless of the spread of the UF_6 since all areas are subject to essentially the same purge rate.

We will assume then that 3000 pounds of UF_6 is released rapidly into the cell floor area and that 1500 pounds of this (or the equivalent hydrolysis products) is purged from the building in the first ten minutes, 750 pounds in the second ten minutes, etc. To simplify calculations, we will assume that all the material leaves the building by way of a single stack of the motor exhaust system at 30°C above ambient temperature. Seventy-five percent of the ventilating air actually leaves by way of the motor exhaust system and the remainder by the roof vents. The conditions described currently prevail in the Paducah 000 buildings. If material changes to the ventilation system result from recent studies, it may be necessary to adjust some of the final figures. As we understand the current proposals, however, these changes should not alter the conclusions.

The reaction of UF_6 and H_2O produces HF and UO_2F_2. HF under normal conditions is a very reactive gas with a strong tendency to adsorb on surfaces. UO_2F_2 is a solid. When UF_6 is released into the atmosphere, it will react with the H_2O adsorbed on any surfaces it comes in contact with. In this case, the UO_2F_2 and some of the HF will never become airborne. The UF_6 will also react with H_2O in the vapor phase. In this case, the UO_2F_2 will be in the form of a dust. The UO_2F_2 particle size will vary depending upon the temperature and the concentration of reactants and the opportunity for agglomeration. Particles larger than a few microns in diameter will settle rapidly due to gravitation. Smaller particles will tend to remain airborne as an aerosol and disperse much as a gas would. The HF, being a gas, will also disperse with strong tendencies to react with or adsorb on most materials it contacts.

The losses of UO_2F_2 and HF by gravitational effects, reaction, and adsorption cannot be estimated with much confidence. We will, therefore, make the conservative assumption that there are no such losses. We have then, as the average for the first ten minutes, the hydrolysis products of 150 pounds of UF_6 per minute in 192,500 cfm air at 30°C above ambient exiting vertically from a 6-ft. by 36-ft. stack at a point 83 feet above ground level. The air and UF_6 products will rise as a result of velocity and buoyancy and eventually level off at a height dependent on these two factors and wind speed. The products will move downwind and disperse in a manner determined by atmospheric stability and wind speed.

We will calculate the effects of this release in terms of the ten-minute average centerline concentration at ground level and at a distance of 1.5 miles from the point of release. This is the minimum distance from the process buildings to residential areas or points of congregation and represents roughly the buffer zone around the plant. We will make the calculations by the following form of the Gaussian dispersion equation:[12]

$$\chi = \frac{Q}{\pi \sigma_y \sigma_z U} \exp\left[-\tfrac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right]$$

where
- χ is average concentration (mg M^{-3})
- Q is release rate (mg sec^{-1})
- σ_y is the horizontal dispersion coefficient (M)
- σ_z is the vertical dispersion coefficient (M)
- U is the average wind speed (M sec^{-1})
- H is the effective height of release (M)

The effective height of release, H, is equal to the actual height plus plume rise, ΔH. We will calculate plume rise from Holland's formula[13] which was developed from steam plant stack observations in the vicinity of Oak Ridge, Tennessee.

$$\Delta H = 1.5\left(\frac{W_o}{U}\right)D + 0.409 \times 10^{-4}\left(\frac{Q_H}{U}\right)$$

where ΔH is the plume rise (M)

W_o is the air exit velocity (M sec^{-1})

U is average wind speed (M sec^{-1})

Q_H is heat emission rate of stack gases (cal.sec^{-1})

D is stack hydraulic diameter (M)

Due to the multiple appearance of U and σ_z in the dispersion equation, there is a particular combination of atmospheric stability and wind speed which maximizes ground level concentration at a given distance from the source. For the particular release we are examining here, the concentration 1.5 miles from the source would be maximized by E and D stabilities with wind speeds of 1.8 and 1.1 M/sec, respectively. At distances greater than 1.5 miles the concentration could be maximized by other stabilities and wind speeds, but it would not exceed the 1.5-mile maximum. In this manner, the maximum possible 10-minute average centerline concentrations are calculated to be 11.9 mg U/M^3 and 4.0 mg HF/M^3, or 5 ppm HF.

At a breathing rate of 3.47×10^{-4} M^3/sec and 100% retention, this would represent doses of 2.5 mg U and 0.83 mg HF due to exposure during the first 10-minute period. Doses for the total release would, of course, be twice as large, or 5 mg U and 1.7 mg HF. The above breathing rate is an accelerated value based on the assumption of appreciable physical exertion. Both the breathing rate and retention level are conservative relative to "standard man" parameters.[18]

Accepting for the present the above concentrations and doses as good estimates of the maximum values, is exposure to such levels permissible? The American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for 1972[1] is 2 mg/M^3 for HF with brief excursions permitted to 4 mg/M^3, which is our estimated maximum concentration. Based on an 8-hour day and a breathing rate of 3.47×10^{-4} M^3/sec, the TLV's would allow, day after day, doses of 20 mg of HF which is far above our estimated total dose of 1.7 mg. It is quite clear that our postulated release of 3000 pounds of UF_6 would present no HF hazard to the public 1.5 miles from the release site.

The situation with uranium, however, is not so clear cut. The TLV for uranium is 0.2 mg/M^3 with excursions to 0.6 mg/M^3. This corresponds to a daily dose of 2 mg. Our estimates indicate a maximum 10-minute average concentration of 11.9 mg/M^3 and a dose from the total release of 5 mg. While these estimates are above the TLV levels, it should be remembered that the TLV limits are based on a permissible continuous daily exposure. We are considering here an incident which may occur once in ten years, twenty years, or perhaps never. It is obvious that for such an event the tolerable one-time exposure would exceed that for a daily event.

Consider the calculated total dose of 5 mg U from our 3000-pound UF_6 release. What would be the effect of such a dose? At the University of Rochester around 1947,[14] six hospital patients were injected with soluble uranium. Doses ranged up to 3.9 mg uranium and were injected directly into the bloodstream. Renal function tests were done before and after the doses were administered. Only at the highest level, 3.9 mg, was there a slight rise in urinary catalase and protein suggesting that tolerance had been reached. In all other cases (up to 2.7 mg uranium), all tests were negative.

At Massachusetts General Hospital around 1957,[15] five terminal brain tumor patients were injected with doses of uranium ranging from 4.3 to 15.8 mg. At 4.3 and 5.0 mg there were no indications that tolerance had been exceeded. At 5.9 mg some indications were detected. At 11.2 and 15.8 mg several positive tests indicating temporary tissue damage were obtained.

The patients died from their terminal illnesses between 2.5 and 556 days after injection. Autopsies revealed no kidney pathology, thus establishing that the damage indicated by tests at the time of injection was temporary. The kidney is, of course, where damage from soluble uranium occurs. An autopsy was not performed on one patient (11.2 mg U) in this group.

To summarize, then, this evidence indicates that a 5 mg dose of soluble uranium received in the bloodstream over a brief period of time might produce clinically detectable evidence of temporary kidney damage. It is indicated that there would be no permanent damage.

As we have modeled the "maximum credible release," then, and calculated maximum concentrations and doses, we could conclude at this point that there would be no problem off site from HF but possibly temporary kidney damage from soluble uranium. There were, however, several conservative factors involved in estimating the concentrations and doses, and in reality, the consequences would be even less serious. The effects of these factors cannot be quantified with any accuracy, but they are nevertheless real and need to be mentioned. For example, we assumed no loss of material, that is, that all UF_6 reaction products would become and remain airborne. In actual fact there would be losses due to surface reaction with dirt, oil, water, etc., and there would be gravitational deposition of the larger UO_2F_2 particles particularly near the release site. Visual evidence of these losses is always apparent around any UF_6 release area. At ORGDP during UF_6 leak detection tests employing releases of several hundred grams, it was found that most of the uranium released as UF_6 in cell housings settled to the floor within a few feet of the point of release.[16] For larger releases, one would expect the fraction settling in the vicinity of the release to decrease but to still be appreciable. Obviously, it cannot be stated with great confidence, but it is believed that one-third to two-thirds of the uranium released from the cascade would "fall out" before traveling 1.5 miles downwind.

In the case of HF, gravitational settling will, of course, not be a factor. However, chemical reaction and physical adsorption are significant. Work has been reported in the literature concerning the reduction of HF concentration near the ground by vegetation.[17] For example, an alfalfa cover 40 cm high reduced steady state concentrations 10 cm above the ground by a factor of 5 from the values 60 cm above the ground. Thus, an appreciable fraction of the HF would probably never reach a location 1.5 miles downwind.

Another conservative factor enters in the calculation of plume rise. There are many different empirical formulas developed to fit a particular situation, stack, etc. The one used here was Holland's formula suggested on the basis of photographs at three steam plants in the vicinity of Oak Ridge. This formula when compared with observed plume behavior in other areas underestimates the rise with the average ratio of calculated-to-observed plume rise being 0.44.[13] This comes about, at least partly, because Holland's photographs followed the smoke only 600 feet downwind. The effect as can be seen in the Gaussian plume equation is to overestimate ground level concentrations or doses.

In calculating plume rise, we assumed a single, isolated motor exhaust stack with an air flow of 192,500 cfm. Actually, this represents only about 3% of the total hot air exhaust from the building. There are many such sources operating simultaneously. The result of ignoring these neighboring heat sources is again to underestimate plume rise and, consequently, to overestimate concentrations and doses.

We have, of course, made our estimations on the basis of a point source. Actually, in case of a real release, the UF_6 and reaction products would undoubtedly leave the building by way of several motor exhaust stacks and roof exhaust vents. It is thus an area rather than a point source. Also, the material would be rather dilute when it left the building. The influence of these last factors would probably be rather small at a distance of 1.5 miles from the source, but they are conservative factors nonetheless.

The total effect of all these factors which affect the accuracy of the earlier concentration calculations cannot be estimated with great confidence, but it is probably in the vicinity of an order of magnitude. Any significant reduction (and certainly an order of magnitude) in the previous estimates would put them in a completely acceptable area.

Aside from the question of the accuracy of the estimations, there are other factors of a practical nature which bear mentioning. It will be recalled that for our release as modeled concentrations were maximized by specific weather conditions. According to records for the Paducah area, weather conditions exist about 75 percent of the time which would yield concentrations less than 50 percent of the calculated maximums.

A second factor is displacement from the plume centerline. For example, with an E stability outside an angle of approximately ±3°, all concentrations would be less than 50 percent of the centerline value. In other words, the area of potential exposure to the higher concentrations is relatively small in stable conditions.

Lastly, there will be a possibility of reducing the amount of UF_6 or products which escape from the building. This could be done possibly with water sprays or by altering the building ventilation mode.

CONCLUSIONS

A model has been developed by which the "maximum credible release" of UF_6 from the cascade is estimated to be 3000 pounds. It is concluded that the model release would pose no significant health hazard to the local population in the vicinity of the Paducah Plant and, consequently, no special containment measures are required in the cascade buildings from this standpoint.

It should be emphasized that this is not to be taken as a prediction of a 3000-pound release of UF_6 in the foreseeable future. The probability or frequency of occurrence of the model release is clearly extremely small. The necessary steps could be summarized as follows:

1. Compressor and associated component failures which proceed to the point of complete seal cavity wipeout (or other area-equivalent cascade rupture).

2. Failure of the compressor to deblade.

3. Continued pumping by the compressor for 3 minutes.

Step 1 has occurred only twice in over twenty years and, actually, has never occurred in 000 equipment. We start, then, with a frequency of less than once per ten years. Vibration detection with automatic shutdown will serve to reduce the extent of damage and will lower this frequency drastically. The probability of such extensive damage without compressor deblade is very small, providing a further reduction. Deblade occurred in both the discussed compressor incidents. And, finally, UF_6 leak detection alarms along with a variety of other indications of trouble make it unlikely that the compressors would be permitted to continue pumping for three minutes.

While a particular value cannot be assigned with any confidence, it is clear that the expected frequency of occurrence of the model release will be very small.

This study considered only the diffusion cascade, not including feed and withdrawal systems. In these areas, where liquid UF_6 is handled, additional factors are obviously present. These facilities will be considered in a subsequent report.

REFERENCES

1. *TLVs, Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1972*, American Conference of Governmental Industrial Hygienists (1972).

2. Breidert, E. C., and J. D. Tate, *Paducah Plant 1960-1961 Uprated Operation in Size "OOO" Equipment*, KY-D-2633, January 23, 1970.

3. Cope, D. G., and J. D. Tate, *Paducah Plant Uprated Operation of Size "OO" Equipment, 1957-1964*, KY-D-2633 Addendum, February 20, 1970.

4. *Report of Investigation of Fire in C-310 Purge and Product Building*, KY-A-201, December 29, 1956.

5. Walter, C. W., *C-335-2.2.8 Compressor Failure*, September 7, 1967.

6. Dew, J. E., and E. H. Tomlinson, *C-331-4.5.10 Compressor Failure*, May 21, 1968.

7. *Final Report of Investigating Committee on Incident at Paducah C-337 Cascade Building December 13, 1962*, ORO-117791.

8. *Hazards of Process Gases in Gaseous Diffusion Plants*, ORO-616, March 30, 1964.

9. Hull, G. T., *Treatment of Process Equipment with Drying Gas*, KY-D-3155, July 17, 1973.

10. Ebel, R. A., *UF_6 Leak Due to Catastrophic Seal Failure at 3300 Horsepower*, K-OA-2018 Draft, July 8, 1971.

11. Ebel, R. A., *UF_6 Leakage Due to Seal Failure*, K-OA-1923, November 10, 1970.

12. Turner, D. B., *Workbook of Atmospheric Dispersion Estimates*, U.S. Department of Health, Education, and Welfare, National Air Pollution Control Administration, Cincinnati, Ohio (1969).

13. Briggs, G. A., *Plume Rise*, U.S.A.E.C., Division of Technical Information (1969).

14. Bassett, S. H., et al., *The Excretion of Hexafalent Uranium Following Intravenous Administration, II, Studies on Human Subjects*, UR 37, July 1948.

15. Luessenhop, J. C., et al., *Am. J. Roentgenol. Radium Therapy Nuclear Med.* 79, 83-100 (1958).

[16] Gentry, W. O., *Personal Communication*, ORGDP, May 26, 1971.

[17] Bennett, J. H., and A. C. Hill, *Adsorption of Gaseous Air Pollutants by a Standardized Plant Canopy*, J. of the Air Poll. Cont. Assoc., Vol 23, No. 3, March 1973.

[18] Slade, D. H., *Meteorology and Atomic Energy 1968*, U.S.A.E.C., Dept. of Tech. Info., July 1968.

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